(2)

AD-A273 812

ARMY RESEARCH LABORATORY

Mitsubishi 3–5 μm IR Imager for Machine-Vision/ATA Applications

by David B. Hillis

ARL-TR-304

November 1993

Approved for public release; distribution unlimited.

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of manufacturer's or trade names does not constitute an official endorsement or approval of the use thereof.

Destroy this report when it is no longer needed. Do not return it to the originator.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
November 1993

3. REPORT TYPE AND DATES COVERED
Final, from 1990 to 1993

4. TITLE AND SUBTITLE
Mitsubishi 3–5 μm IR Imager for Machine-Vision/ATA Applications

5. FUNDING NUMBERS
DA PR: D650
PE: P65709

6. AUTHOR(S)
David B. Hillis

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
Attn: AMSRL-SS-IC
2800 Powder Mill Road
Adelphi, MD 20783-1197

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-TR-304

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Materiel Command
Deputy Chief of Staff for Intelligence
5001 Eisenhower Ave
Alexandria, VA 22333-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
AMS code: P665709.6500012
ARL PR: 6E8061

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Presented in this report are the results of a study conducted to test the performance of the Mitsubishi model 5120C IR Imager as part of an automatic target acquisition (ATA) system. The study was conducted in two phases. The first was directed toward a detailed analysis of the images produced by the Mitsubishi sensor, with the aim of identifying any artifacts or characteristics that might elude the human observer but still affect the ATA system's performance. The second phase involved extensive field testing using the Mitsubishi sensor with two ATA systems: one based on the VME (Versa Module European) bus standard and the other based on a PC.

The Mitsubishi sensor showed very good performance in almost all tests and appears to be an excellent choice for ATA/machine-vision applications. Frame-by-frame analysis of digitized image sequences from the Mitsubishi sensor failed to uncover any hidden problems, and several weeks of field testing with two different ATA systems demonstrated high-quality performance.

14. SUBJECT TERMS
FLIR, automatic target acquisition

15. NUMBER OF PAGES
18

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

Contents

Figures

1. Introduction

1.1 Purpose

Presented in this report are the results of a study conducted to test the performance of the Mitsubishi model 5120C IR Imager as part of an automatic target acquisition (ATA) system.

The Mitsubishi sensor is an infrared imaging device with a standard video (RS 170) output. It uses a 512×512-element platinum silicide (PtSi) staring array, with a germanium lens, and is sensitive to radiation in the 3–5 μm band of the infrared. The detector is cooled to 77 K, and the net equivalent temperature difference (NETD) is 0.15°C. A 50-mm germanium lens, with a field of view of about 11° by 14°, was used throughout the study.

The model tested, 5120C, has two separate modules, a camera head weighing 7.5 kg and a controller box weighing 13 kg. It draws 250 W of power. A new model, the IR-M500 IR Imager, is now available as an off-the-shelf item. The IR-M500 is advertised to give performance identical to that of the 5120C, but at about a third the size and half the weight.

1.2 Study Description

The study was conducted in two phases. The first was directed toward a detailed analysis of the images produced by the Mitsubishi sensor, with the aim of identifying any artifacts or characteristics that might elude the human observer but still affect the ATA system's performance. A field test was conducted to gather representative data from the Mitsubishi sensor; a Kollmorgen MicroFLIR and a Sony video camera were used for comparison. The data (image sequences) were recorded onto an optical disc for frame-by-frame processing on a Sun computer. Tests performed included measurements of system noise and image stability, as well as simulations with both a simple motion-detection algorithm and a complete simulated tracker.

The second phase involved extensive field testing using the Mitsubishi sensor with two ATA systems: one based on the VME (Versa Module European) bus standard and the other based on a PC.

2. Background

2.1 Motivation

There are numerous military applications for infrared sensors as part of automated or semi-automated systems (i.e., site surveillance systems, perimeter defense systems, robotic or remotely piloted vehicles, automatic target-recognition and machine-aided target-recognition systems, etc). The infrared sensors available today are unsuitable for most of these applications because of their high cost or low performance.

Currently, there is a broad array of relatively new infrared sensor technologies. The U.S. Army has a strong interest in identifying both low-cost infrared technologies for the long term, and moderate-cost sensors for the near term.

2.2 Representative Application

The goal of the program was to evaluate the performance of the Mitsubishi sensor for machine-vision/ATA applications. The sensor was tested against the requirements of the ARL robotics program, as these were considered to be fairly representative of a broad range of applications.

The ARL robotics program's ATA system is designed to operate on a robotic vehicle in a reconnaissance, surveillance, and target acquisition (RSTA) mission; it automatically detects and tracks tank-sized vehicles at ranges out to 2 km using both forward-looking infrared (FLIR) and visible-light cameras. It must observe an area from a stationary position for hours or days, reporting to a remote operator when and only when a person or vehicle appears in its area of coverage. It uses motion (indicated by a change in image intensity) as its primary discriminant, but it can handle targets that move and then stop or that move straight towards it.

2.2.1 ATA Algorithms

The ATA system's image-processing algorithms are identical for black and white video cameras and infrared sensors. In the first phase, each new image is compared to a reference image. The reference or background image is adjusted slowly over time—quickly enough to reflect changing lighting (temperature) conditions in the scene, but not so quickly as to be affected by transient targets. Regions in the image that have relatively large differences in intensity between the new image and the reference may contain moving targets. (Such regions might also be caused by shadows, reflections, wind-blown vegetation, dust, animals, etc.)

Once these regions are identified, they are examined for subregions of uniform motion. This step helps to separate targets from dust, exhaust, etc, and targets partially occluding other targets, as well as eliminating some sources of false alarm. These subregions are then passed to the tracker.

The tracker uses a range map (generated with input from the operator during setup) to filter out subregions that are too large or small. This greatly reduces the rate of false alarms from birds and small animals. A bird or even a flying insect sufficiently close to the sensor can appear larger than a vehicle further away. Generally, however, they will appear in a part of the image where their apparent size or speed (as determined from the range map) is inconsistent with what would be expected from a real vehicle.

The remaining subregions are used to create or update existing track files. As part of the track association process, a correlation process is applied that tests how closely the subregions match with the pre-existing tracks.

2.2.2 *Sensor Artifacts*

The ideal sensor would be one in which regions of the image without moving targets showed no changes in intensity over time, and in which an object appeared exactly the same wherever in the image it moved. Of course, real scenes and objects tend to change with time in the visible or infrared, so no sensor could meet this ideal. However, real sensors corrupt the images they produce with certain artifacts that can tend to move their performance further from the ideal.

Typical artifacts include *jitter* (where the whole image shakes as though the sensor were vibrating), *scan lines* (where bright and dark horizontal bands move across the image), and *image nonuniformity* (such as results from uneven sensitivity from one pixel to another on a detector array). These and other artifacts are easily compensated for by the human visual system but can cause errors, reduce sensitivity, or require costly additional processing in machine vision applications.

2.3 3–5 versus 8–12 μm

The Mitsubishi sensor is sensitive to IR radiation in the 3–5 μm band, while most fielded sensors are sensitive at 8–12. Although images from sensors in either band will usually look quite similar, some situations will produce marked differences.[1,2]

[1] *Henry Sadowski, Atmospheric Transmission Factors Affecting FLIR Performance in the 3–5 and 8–12 μm Spectral Bands and Predicted Performance of a PtSi FLIR in the 3–5 μm Band, Loral Fairchild Systems (January 4, 1991).*

[2] *Infrared Information Analysis Center, Methodology for Comparing 3–5 μm and 8–12 μm Sensors, Technical Review 92-02, Spectral Reflections 22, No. 2 (May 1992).*

At first examination, it might appear that a sensor operating in the 8–12 μm region of the infrared spectrum would always have an advantage over one operating in the 3–5 μm region. Objects typically radiate more energy in the 8–12 μm band, and the atmospheric window has less attenuation. In fact, the performance of a sensor in either band is a complicated function of target temperature, atmospheric conditions, range, and of course the characteristics of the sensor itself.

In general, a relatively cold target close to the background temperature will be easier to detect at 8–12 μm. As the target temperature increases, its detectability in the 3–5 μm band increases. (In the experience of the ARL robotics program, moving vehicles and personnel always generate enough heat to provide high contrast with most backgrounds in either band.)

Under dry conditions, atmospheric attenuation is much less at 8–12 μm than at 3–5 μm. As the water in the atmosphere increases, the attenuation in the 8–12 μm band increases faster than it does in the 3–5 μm band. For high humidity levels, the atmospheric attenuation can be higher at 8–12 μm than at 3–5 μm, but this will usually be more pronounced at ranges beyond a few kilometers. Some kinds of fog and haze also attenuate one band more than another.

Unlike the 8–12 μm band, the 3–5 μm band includes part of the solar radiation reflected from an object (typically referred to as "solar clutter"). For daytime operation, this fact can have important consequences. A vehicle at ground temperature is likely to have a reflectance different from the background and so may be more easily detected in the 3–5 μm band. It is far more likely, however, that the solar clutter (as the name implies) will work to the disadvantage of an ATA system in the 3–5 μm band. Scintillation from highly reflective objects and shadows from clouds passing between the ground and the sun can cause rapid changes in intensity in regions of the image that are easily mistaken for moving objects. This well-known phenomenon is easily observable in the Mitsubishi sensor, as well as others operating in the 3–5 μm band.

A sensor in the 3–5 μm band will also be much more sensitive to fires, flares, headlights, etc, which can be good or bad depending on the application.

In actual practice, and at ranges of less than 2 km, the ARL ATA systems' performance has usually been limited by factors such as number of pixels on target, sensor artifacts, and the type of clutter in the scene, independent of the infrared band used.

3. Exploitation Data

The exploitation was carried out in two phases. The first phase consisted of frame-by-frame analysis of the Mitsubishi sensor images in the laboratory. The analysis was qualitative rather than quantitative, with the goal of discovering the presence of any pronounced artifacts produced by the Mitsubishi sensor that, while perhaps insignificant to a human observer, might cause problems for an ATA system.

The second phase involved extensive field testing of the Mitsubishi sensor with two real-time ATA systems under a variety of conditions.

3.1 Lab Analysis: Fort A. P. Hill Data

A field data collection exercise was conducted at Fort A. P. Hill in which boresighted and time-coded video data were collected for vehicles moving across a natural background. Video and time-code data were recorded on VCR tape for the Mitsubishi sensor, as well as for a Kollmorgen MicroFLIR and a Sony model XC-77 black and white video camera. Select portions of these data were stored on an optical disk for frame-by-frame examination.

The image sequences from the optical disk were processed on a Sun 4 computer running KBVision (an image-processing/understanding software package) and several C language programs developed by ARL. The purpose of the analysis was to establish the presence or absence of serious artifacts in the Mitsubishi sensor that would hinder the performance of an ATA system. The data from the other two sensors were used for rough comparison, since they had both been used in numerous field exercises and their performance with the robotics program's ATA systems was well understood.

3.1.1 Image Differencing

The program xAPHim.c was written to test the performance of the three sensors under a simple differencing algorithm. It reads a sequence of images off an optical disk, takes the first image as the reference, and then takes the absolute value of the difference between that reference image and each succeeding image. The maximum, minimum, and average of these absolute values are recorded for each image. These absolute values are then compared to an operator-supplied threshold. Each image is displayed on the computer, with the pixels where the threshold was exceeded (presumed to correspond to moving objects) shown with maximum brightness.

The program was used to look for any significant difference in the general noise levels in the sensors, as well as to observe how successfully the threshold could separate out the moving targets from the background. The noise measurements of the three sensors all fell within the same general range of values. The quality of the target/background separation varied greatly, but roughly corresponded with the image contrast, which was highly context dependent for each sensor. For example, when a moving tank was buried in a large cloud of dust, the program, using the Sony camera images, detected the entire moving cloud of dust. The two FLIR's, for whom the dust was invisible, detected only the tank. All the targets (fairly hot vehicles) were detected about equally well in image sequences from the Mitsubishi and Kollmorgen sensors.

3.1.2 *Image Stability*

The program xAlign.c was written to test the stability of the sensors. Using an image stabilization routine (given a reference image, it tests to see how far each successive image is shifted from it), the program tested for image "jitter" or any other artifact that could cause an apparent shift. The image sequences from all three sensors were found to be stable according to this test to at least the width of one pixel.

3.1.3 *Pixel Uniformity*

The Mitsubishi sensor shows some minor pixel nonuniformity. The program xTracker.c was written to test whether this pixel nonuniformity was sufficient to degrade tracking performance compared to the other sensors. This program uses a correlation-based algorithm to search for and track a target through a sequence of images. The operator enters a box around the target in the first image, and the program searches subsequent images to find the region that best correlates with (matches) it.

Nonuniformity across the image would tend to degrade the performance of this tracker because an object in one part of the image would not correlate as well with the same object seen in another part of the image (it would look different). In all cases, the Mitsubishi sensor tracked the object as well as or better than the other sensors.

3.2 ATA Simulation

A computer simulation of the robotics program's complete ATA system was used to evaluate the performance of the three sensors against the most challenging segment from the collected video data. Although the environment at Fort A. P. Hill is fairly benign for image-processing applications, the segment chosen was challenging in that the target, an M60 tank, reached a maximum range of 1.5 km (fairly long range for a 14° field of view), was often partially or totally obscured by the terrain, and was engulfed in a cloud of dust for much of its path.

This test proved to be less challenging than expected, as the tracker simulation gave essentially perfect results for both the Mitsubishi and the Kollmorgen data.

3.3 Typical Imagery

Figures 1 to 3 show images produced by the Mitsubishi sensor, the Kollmorgen MicroFLIR, and the Sony video camera looking at the same scene at the same time. The images are of an M60 tank at 1 km (middle right) moving on a dirt road at Fort A.P. Hill at midmorning. The Mitsubishi image (fig. 1) is magnified so as to appear at roughly the same scale as the other two images. Figures 4 and 5 show an image from the Mitsubishi sensor in which the tank has moved to about 1.5 km away.

Both of the infrared images would appear quite different at night, but particularly the one from the Mitsubishi. Differential solar heating causes bare earth to shine more brightly than grass-covered earth in both the 3–5 and the 8–12 μm bands. In the Mitsubishi image, however,

Figure 1. Mitsubishi infrared image of M60 tank at Fort A. P. Hill.

Figure 2. Kollmorgen infrared image of M60 tank at Fort A. P. Hill.

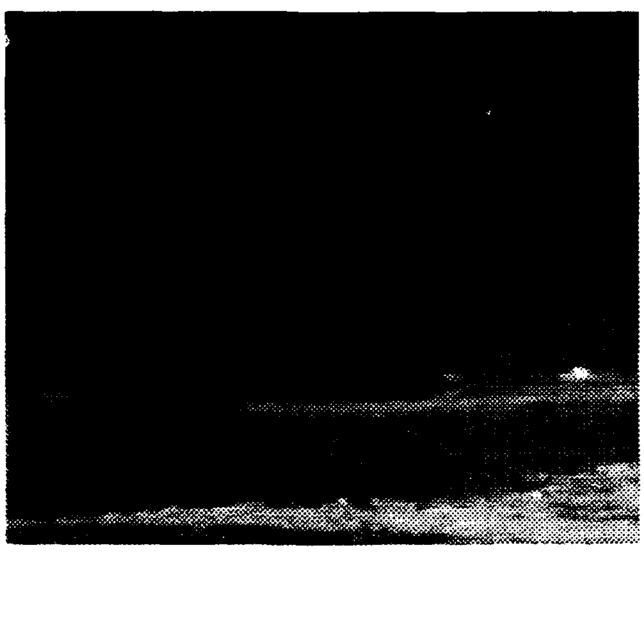


Figure 3. Sony video image of M60 tank at Fort A. P. Hill.

Figure 4. Mitsubishi infrared image of tank at 1.5 km.

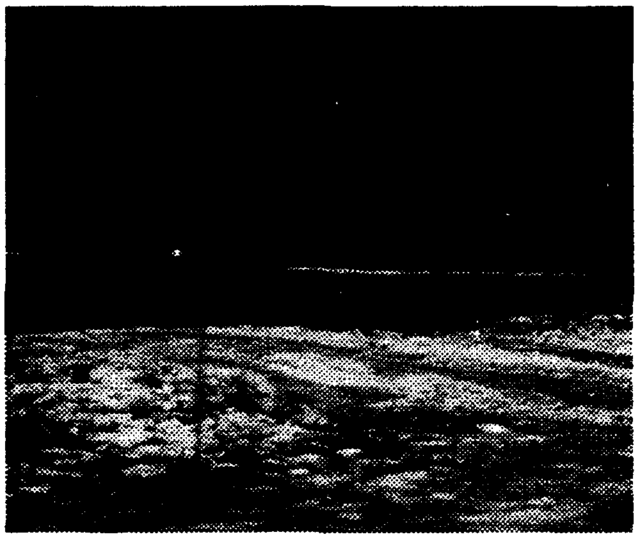
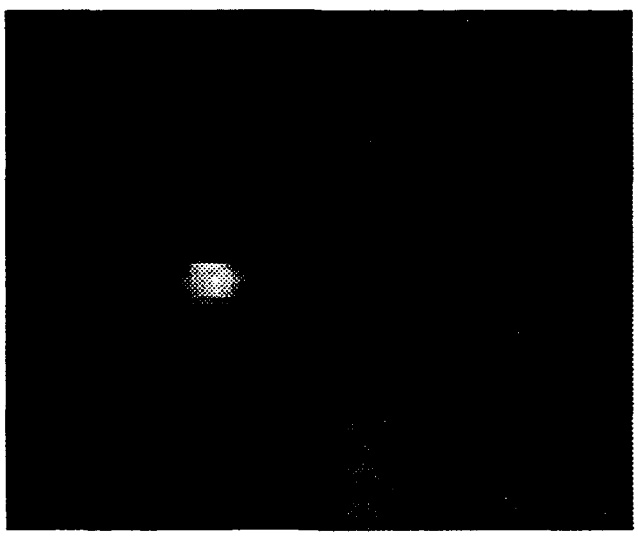


Figure 5. Detail of figure 4 showing tank.



reflected solar radiation increases the contrast and also highlights the clouds (top of fig. 1). At night, there is no reflected solar radiation, and the ground temperature is more uniform.

3.4 Field Testing

The most conclusive test of the Mitsubishi sensor's performance as part of an ATA system was obtained by the common-sense procedure of using it as part of an ATA system over a period of time and observing the results. The evaluations were entirely subjective: it is clear to an observer when an ATA system is performing well and when it is performing poorly.

During the course of a two-week demonstration (OSD Demo I) at the Churchville test track at Aberdeen Proving Grounds and during tests at other sites, two Mitsubishi sensors were tested side by side. One sensor was connected to a relatively simple PC-based ATA system, and the other was connected to a sophisticated VME-based system. All the targets moved at least once during each test. The results from the Mitsubishi were compared to those obtained earlier in similar tests using the Kollmorgen MicroFLIR.

3.4.1 *VME Tracker in Field*

The Mitsubishi sensor and VME tracker were tested at several sites at many different times of day and weather conditions; tracked and wheeled vehicles and walking men were used for targets. The performance was excellent in all cases.

The tracker is not perfect, however. In particular, it often has trouble with scenes including a lot of wind-blown vegetation or moving animals and with targets that subtend less than about 4 pixels across, regardless of the sensor used. The test cases used, for the most part, avoided these extremes.

3.4.2 *Night Tests*

Three night tests were conducted with the Mitsubishi sensor and the VME tracker, one with walking men and two with high-mobility multipurpose wheeled vehicles (HMMWV's) as targets. In all cases, the target-to-background contrast was higher, and target detection was easier than for the same scenarios conducted during daylight hours.

Without the effect of differential solar heating, the background cools off, approaching a uniform temperature. Although targets remain warm and readily distinguishable, individual features of the background become hard or impossible to distinguish in the infrared image (this effect should be more pronounced in the 3–5 μm band than in the 8–12). A moving vehicle quickly acquires a bright infrared signature as the tires or tracks heat up from friction. Eventually, the engine compartment heats up enough to increase the signature still more. Similarly, people tend to be significantly warmer than their nighttime background.

For an application such as ATA, where the objective is to separate active targets from the background, this effect is beneficial. For applications in which it is necessary to detect features of the background, such as night driving (which is beyond the scope of this project), it would most likely be preferable to select a sensor in the 8–12 μm band. A few hours after dark, and on foggy mornings, terrain features such as road edges sometimes became completely invisible to the Mitsubishi sensor.

3.4.3 *PC Tracker in Field*

The Mitsubishi sensor was tested with a PC-based tracker alongside the VME tracker so that its performance could be measured with a significantly simpler and less expensive system. The PC-based tracker is similar to the VME tracker, but it runs on smaller, cheaper, less powerful hardware, is slower, and does not include all the VME tracker's features. In particular, it does not implement an algorithm developed by the Sandia National Laboratory called "MAMAD," which helps avoid false alarms caused by cloud shadows, dust, etc, by comparing the image intensity difference for each pixel with those in a large neighborhood of pixels around it.

The tracker performed well under almost all conditions encountered with one significant exception. A common weather pattern in the afternoon is bright sunshine with high clouds, causing fast-moving shadows to appear on the ground. These cloud shadows cause rapid changes in intensity in regions of an image formed by a visible-light video camera. When the PC-based tracker was tested with a video camera under these conditions, it invariably performed terribly, with numerous false alarms.

Because of the solar clutter (reflected sunlight impinging on the 3–5 μm band), cloud shadows cause the same problems in the 3–5 μm band as in the visible. When the PC-based tracker was tested with the Mitsubishi sensor under these conditions, its performance was no better than with the Sony video camera.

Sensors operating in the 8–12 μm band are free of this problem entirely. Since the VME-based tracker was observed to be free of false alarms from cloud shadows whether the Sony video camera or the Mitsubishi sensor was used, it can be concluded that the solar clutter problems can be solved at the price of additional computation (essentially a 16×16-pixel convolution across the image for each image processed).

4. Conclusions

The Mitsubishi sensor showed very good performance in almost all tests and appears to be an excellent choice for ATA/machine-vision applications. Frame-by-frame analysis of digitized image sequences from the Mitsubishi sensor failed to uncover any hidden problems, and several weeks of field testing with two different ATA systems demonstrated high-quality performance.

The one liability observed was the fact that the Mitsubishi sensor, because it operates in the 3–5 μm range, is sensitive to solar clutter (reflected sunlight from objects in the scene). For the ATA systems tested, solar clutter effects from cloud shadows could cause unacceptable levels of false alarm. However, these false alarms could be virtually eliminated by the addition of an extra image-processing step.

Distribution

Administrator
Defense Technical Information Center
Attn: DTIC-DDA (2 copies)
Cameron Station, Building 5
Alexandria, VA 22304-6145

Defense Intelligency Agency
Attn: DSP-2A
Washington, DC 20340

Commander
U.S. Army S&T Center Far East Office
Attn: AMSMI-J-OP
APO San Fransico, CA 96328

Commander
AMC Scientific & Technical Information
Team-Eruope
Attn: AMXMI-E-OP
APO, New York 09079-4734

Headquarters USAMICOM
Attn: AMCPM-UG
Redstone Arsenal, AL 35898-8060

HQDA, ODCSOPS
Attn: DAMI-FIT
Washington, DC 20310-1001

Commander
U.S. Army CECOM
Attn: AMSEL-MI-I
FT Monmouth, NJ 07703-5000

Director
U.S. Army Missile Space
Intelligence Center
Attn: AIAMS
Redstone Arsenal, AL 35898-5000

Commander
U.S. Army Armament RD&E Center
Attn: SMCAR-ASF
Picatinny Arsenal, NJ 07806-5000

Commander
Foreign Intelligence Office
Attn: AMSRL-OP-IS-FI
Charlottesville, VA 22901-5396

U.S. Army Signals Warfare Center
Attn: AMSEL-RD-IEW-OPP
Vint Hill Farms Station
Warrenton, VA 22186-5000

Commander
U.S. Army Test & Evaluation Command
Attn: AMSTE-SI-F
Aberdeen Proving Ground, MD 21005-5055

U.S. Army Training & Doctrine Command
Attn: ATCD-I
FT Monroe, VA 23651-5170

U.S. Army White Sands Missile Range
Attn: STEWS-FI
White Sands Missile Range, NM 88002-5001

U.S. Belvoir RDE Center
Attn: STRBE-TY
FT Belvoir, VA 22060-5606

Director
U.S. Army Research Laboratory
Attn: AMSRL-OP-IS-FI
Aberdeen Proving Ground, MD 21005

Director
U.S. Army Research Laboratory
Attn: AMSRL-WT-WC, J. Bornstein
Attn: AMSRL-WT-PB, E. Schmidt
Aberdeen Proving Ground, MD 21005-5066

U.S. Army Research Laboratory
Attn: AMSRL-OP-CI-AD, Library (3 copies)
Attn: AMSRL-OP-CI-AD, Mail & Records
Mgmt
Attn: AMSRL-OP-CI-AD, Tech Pub
Attn: AMSRL-OP-IS-FI

Distribution (cont'd)

U.S. Army Research Laboratory (cont'd)
Attn: AMSRL-SS, V. DeMonte
Attn: AMSRL-SS-IP, T. Mills
Attn: AMSRL-SS, J. Sattler

U.S. Army Research Laboratory (cont'd)
Attn: AMSRL-SS-I, J. Pellegrino
Attn: AMSRL-SS-IC, D. Hillis (30 copies)